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5G CHALLENGES FOR CONNECTED, COOPERATIVE AND AUTOMATED TRANSPORT SYSTEMS

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DATE 2018 Special Session:

Designing Autonomous Systems: Digitalization in Automotive and Industrial Systems

Berlin, March 22nd 2018

Cti
Commission des Titres d'Ingénieur

Cooperative vs. Automated vs. Autonomous

- **Confusing Concepts...**
  - Autonomous Car – a car, which driving dynamics are based on its own sensor and intelligence, without the assistance of any external information
  - Automated Car – a car, which driving dynamics are based on its own sensors and intelligence, potentially enhanced with external support (data, human)
  - Connected Car – a car capable of obtaining external information or exchange information with other cars or infrastructure
  - Cooperative Car – a car, which telematics system collaborate with other systems to reach a common global goal.

- **What are we 'really' aiming at ?**
  - (maybe) Cooperative Connected Automated Vehicles
    - Vehicles will require external information to drive autonomously
    - Full autonomous driving is highly unlikely (under global context)

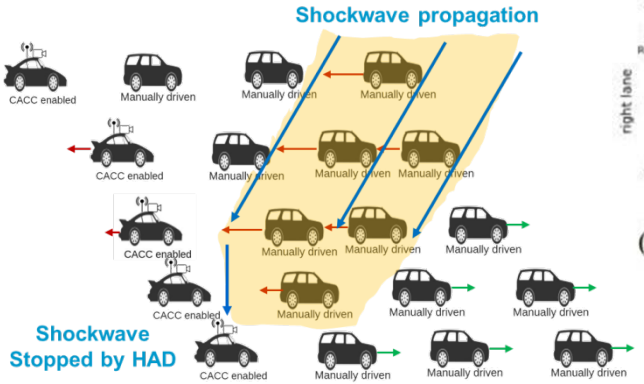
Automated Transport Systems (ATS)

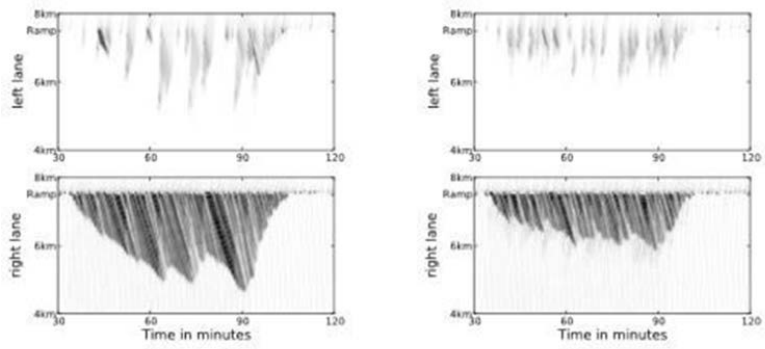
- **Expected to radically change the automotive Industry**
  - Autonomous Cars & Platooning expected to appear next decade
  - Automated vehicles are yet not limited to cars and trucks

- **Benefits of Automated Vehicles**
  - Estimated 585,000 lives between 2035-2045
  - Massive economic opportunity (> 7 trillion $ - Intel)
  - 250 million hours of consumers' commuting time per year
  - Price of Safety - Priceless

Cooperative Connected ATS – Benefits and Challenges

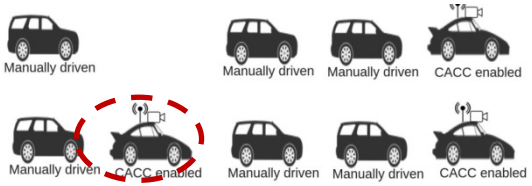
- **Intercept Shockwave**
  - CATS anticipate speed reduction
  - CATS stops shockwaves already at low penetration

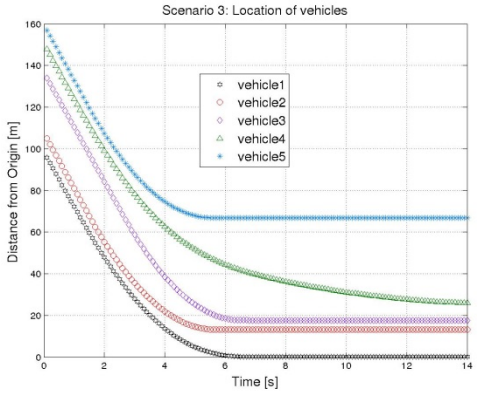




Source: Markus Forster et al., IEEEInfocom, 2014

- **Increase Capacity**
  - CATS require less inter-distance
  - CATS may use the inter-distance of other cars
    - at no impact on safety

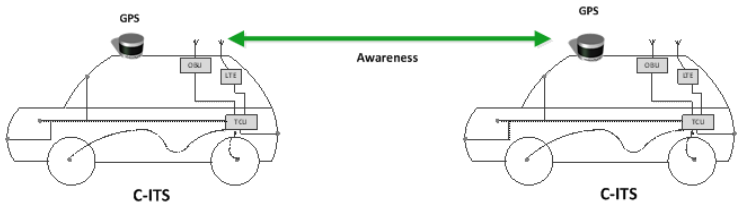




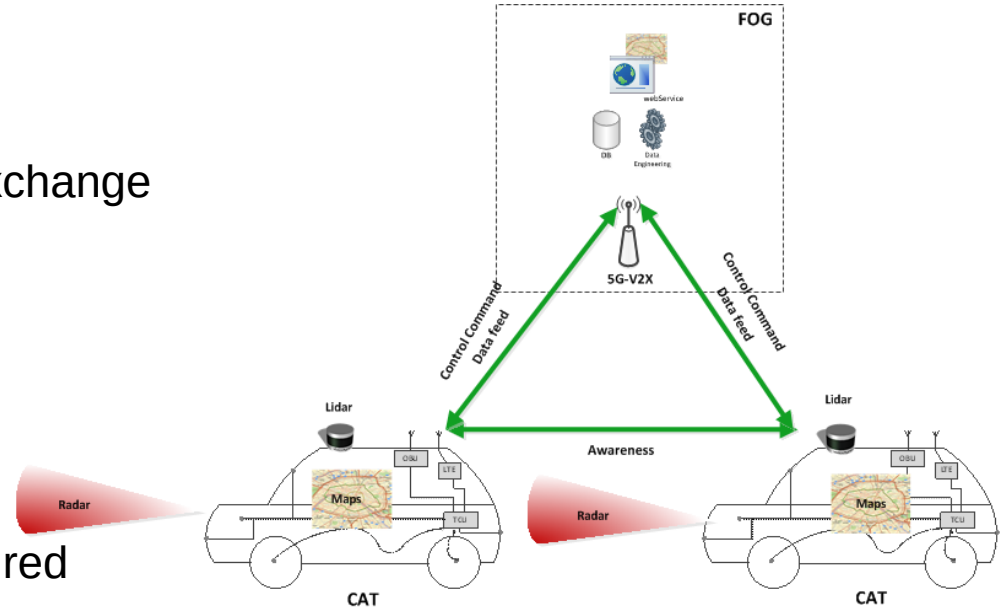
Percentage penetration of APs	0	20	40	60	80	100
Collisions Avoided	0	1	11	35	57	61

Cooperative Connected ATS – Benefits and Challenges

- **Connected Cars**
  - Mostly focused on Awareness
  - V2V



- **Connected 'Automated' Cars**
  - Require large amount of data exchange
    - Map synchronization
    - Environmental information
    - Control Command
    - …
  - V2V must be cranked up
  - V2I becomes critical
    - Robust Core Network Required



Automated Vehicles vs. Remote Control Vehicles

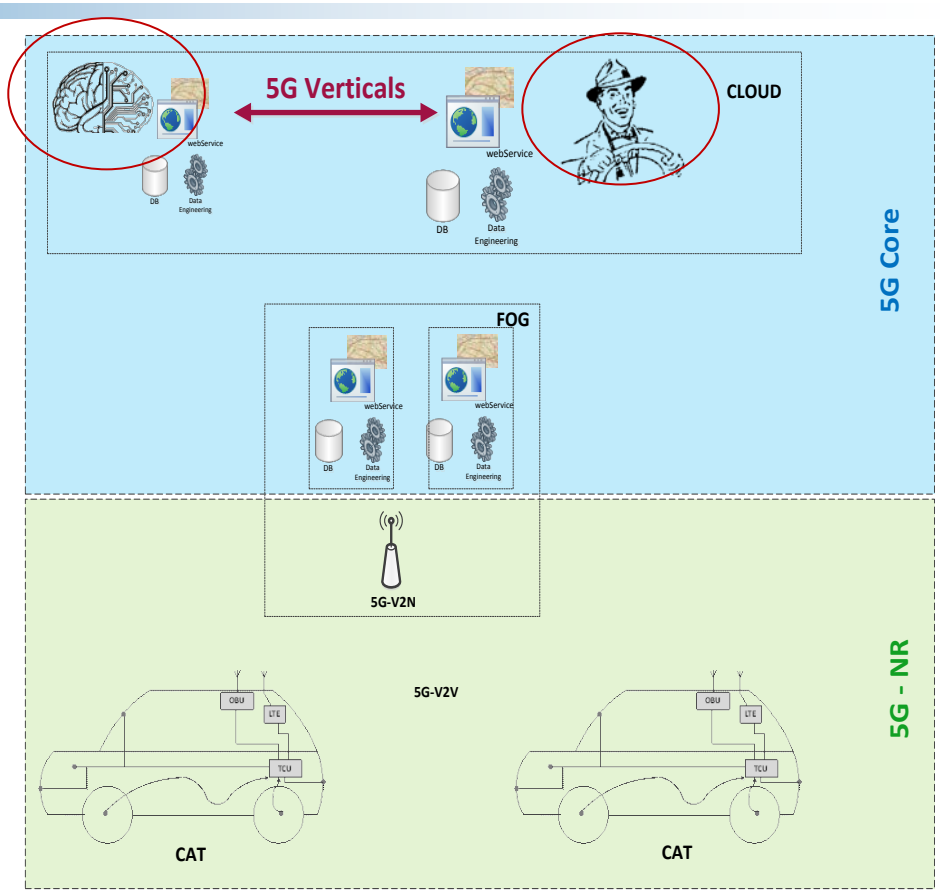
- **Joint EURECOM, BUPT, CHINA Mobile Demo**
  - Actually: 4G only ☺

https://youtu.be/7IGewzVH-Ro

https://youtu.be/rdWhQoO0EYo

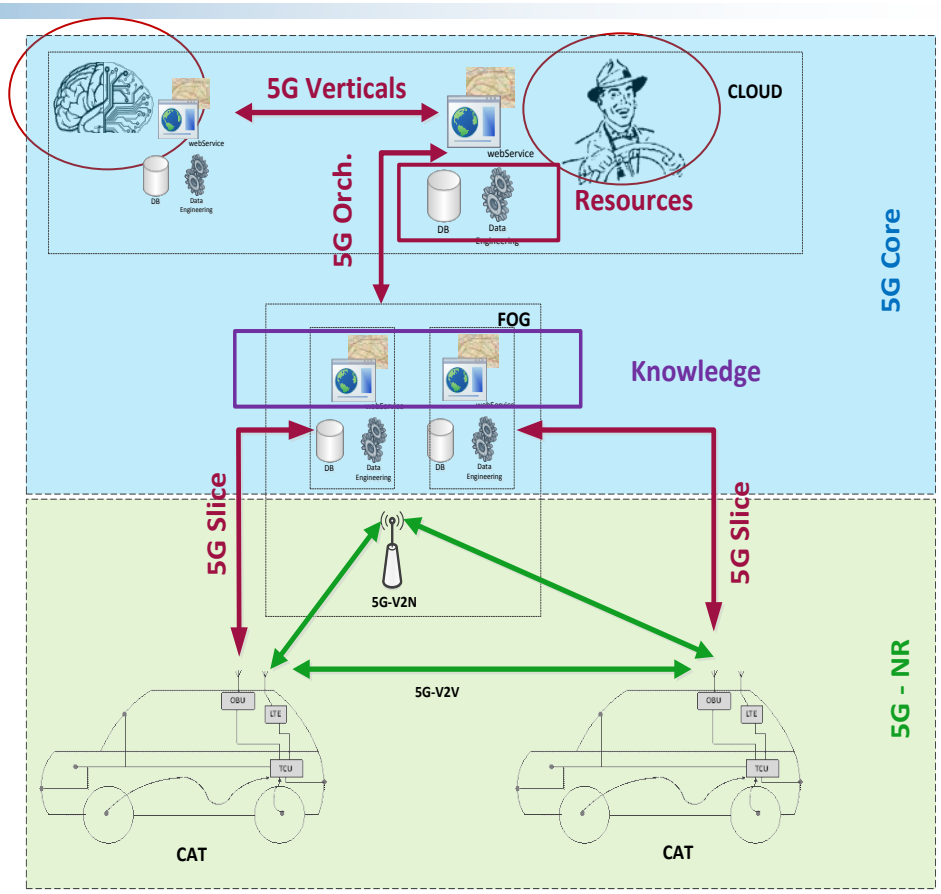
5G Challenges - Automated Vehicles vs. Remote Control Vehicles

- **5G Challenges:**
  - Remote Driving & Automated Driving two Verticals
  - AI or Human control similar from a functional point of view



5G Challenges - Automated Vehicles vs. Remote Control Vehicles

- **5G Challenges:**
  - Remote Driving & Automated Driving two Verticals
  - AI or Human control similar from a functional point of view
  - Require:
    - URLL - 5G V2X
    - Dynamic Resources - 5G NFV & SDN
    - Knowledge – Content-Centric Networking
    - …



V2X Technologies

CURRENT TECHNOLOGIES

WiFi-V2X - ITS-G5

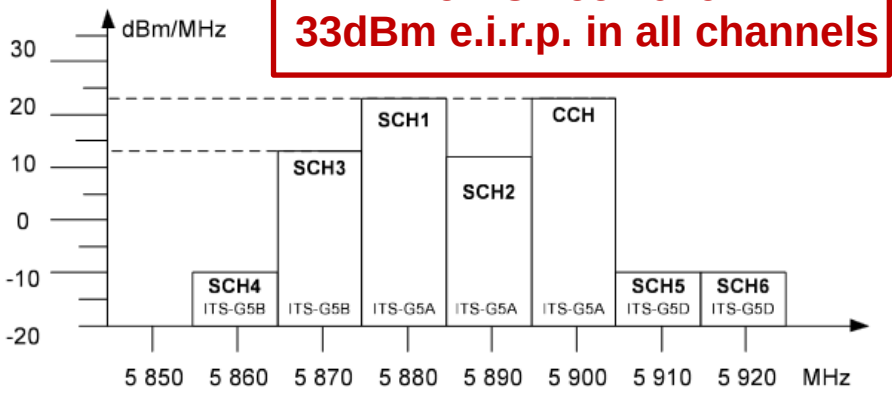
- **Specification completed in 2010 (IEEE 802.11p-2010)**
  - Later integrated in IEEE 802.11-2012
- **Key characteristics**
  - 5.9 GHz frequency domain
  - Based on IEEE 802.11a (OFDM PHY)
  - 10 MHz channel bandwidth
  - Rates: 3, 4.5, 6, 9, 12, 18, 24, 27 Mbps
  - Operates without a BSS

CAR 2 CAR
COMMUNICATION CONSORTIUM

- **ITS/ATS Frequency Band**

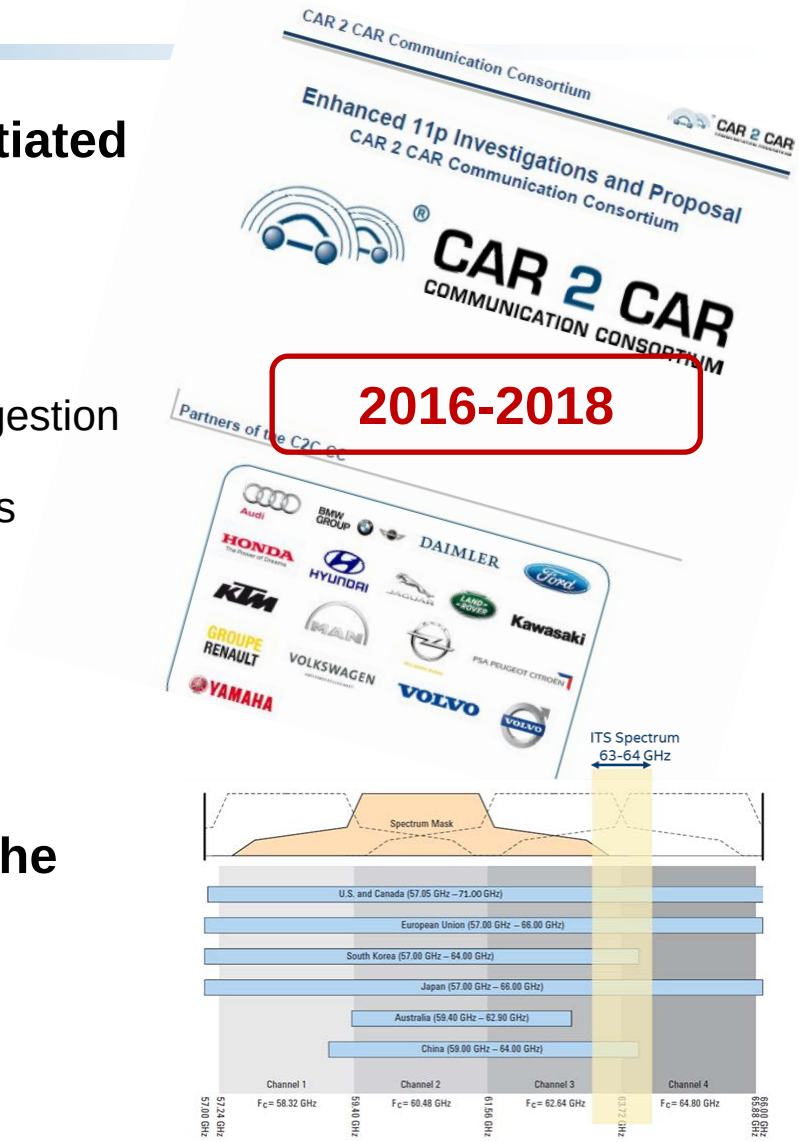
Name	Center Frequency	Type
SCH6	5920	ITS-G5D - Future ITS
SCH5	5910	
SCH4	5860	ITS-G5B - Non-Safety related
SCH3	5870	
SCH2	5880	
SCH1	5890	ITS-G5A - Safety-Related
CCH	5900	

New since 2016 !!
33dBm e.i.r.p. in all channels



ITS-G5 Release 2 – Design Directions

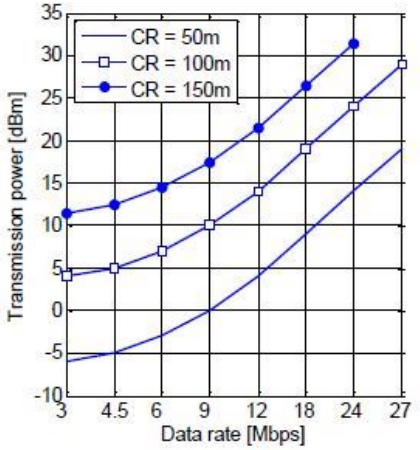
- **In November 2016, the CAR 2 CAR initiated a WI on ITS-G5 Rel. 2**
  - CAR 2 CAR white paper – “Enhanced 11p Investigations and Proposal”
- **Design directions:**
  - Enhanced channel usage (modulation, congestion control)
  - Enhanced information exchange (Tx what is ‘required’)
  - Enhanced PHY & MAC
  - Enhanced Capacity
    - mmWAVE bands



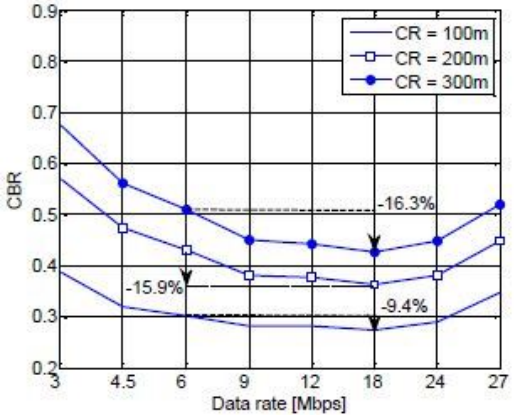
- **Input currently under discussions at the CAR 2 CAR**
  - Objectives:
    - > 5dB gain at 5GHz
    - 10x capacity at 60Hz

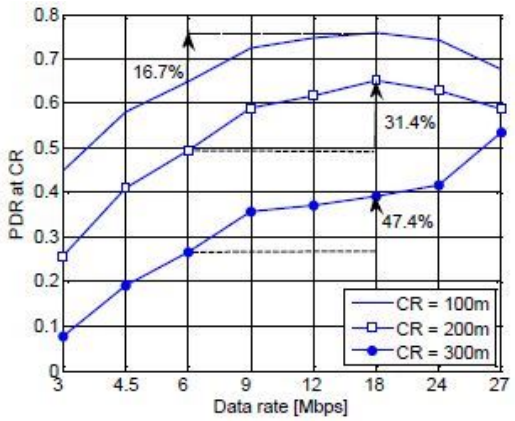
ITS-G5 Release 2 – Enhanced Channel Usage

- **Principle:**
  - Joint adjustment of Tx power and data rate to optimize the channel occupancy ‘footprint’
    - In a nutshell: considers the impact of Tx power in perturbing remote neighbors
  - Objective: adjusting Tx power (and modulation) to guarantee a 95% PDR at a given TX range



- **ITS-G5 default 18 mbps on CCH**
  - The Channel Load (CBR) is reduced by 9%-16% as function of the intended distance
  - The Packet Delivery Ratio is improved by 16%-47%





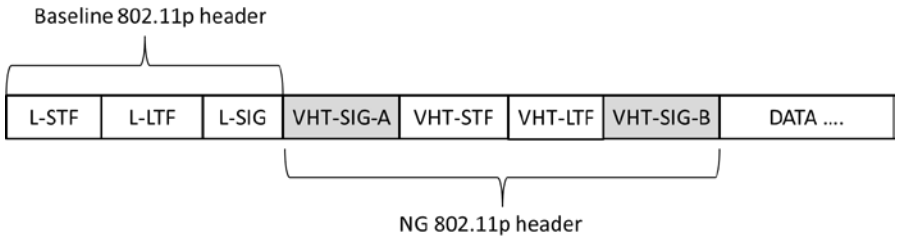
Source: M. Sepulcre, J. Gozalvez, B. Coll-Perales "Why 6Mbps is not (always) the Optimum Data Rate for Beaconing in Vehicular Networks", IEEE Transactions on Mobile Computing

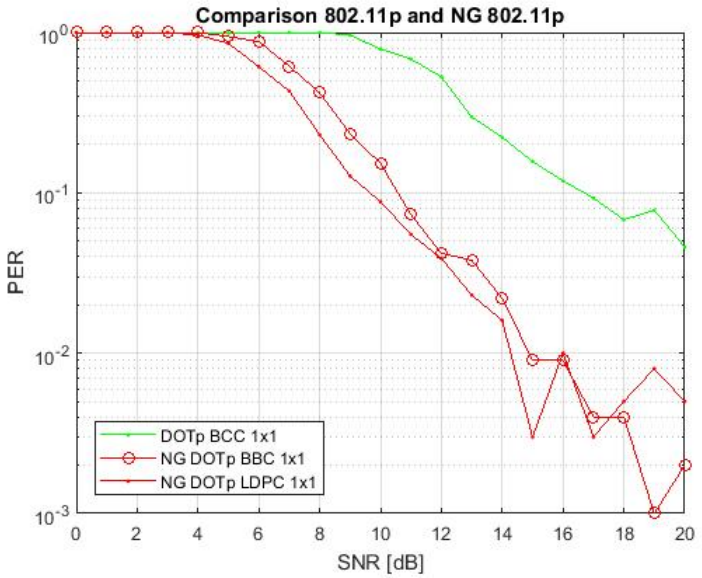
802.11 for Next Generation V2X Communication

- **IEEE 802.11 new Study Item created on <u>March 9th 2018</u>**
  - Following the proposal from the CAR 2 CAR
  - Take the state-of-art IEEE 802.11 technology (IEEE 802.11ac)
    - Turn it half-clock (10Mhz)

<u>Disclaimer</u>: All current C-ITS applications can be handled by **ITS-G5**. This **new SI** is to match the **future** 5G-V2X for next **Generation C-ITS**

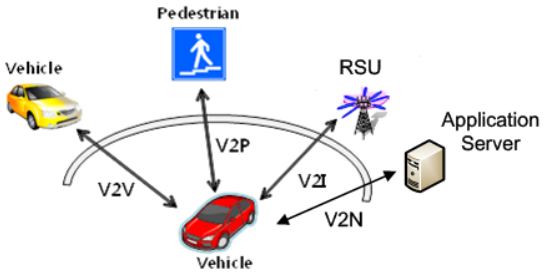
  - Potential Innovations:
    - Advanced Channel Estimation
    - LDPC codes
    - Space-Time Block Codes (STBC)
    - Higher Modulation & Capacity
    - Multi-Channel managements
  - <u>Release</u>: rather fast, probably end 2018



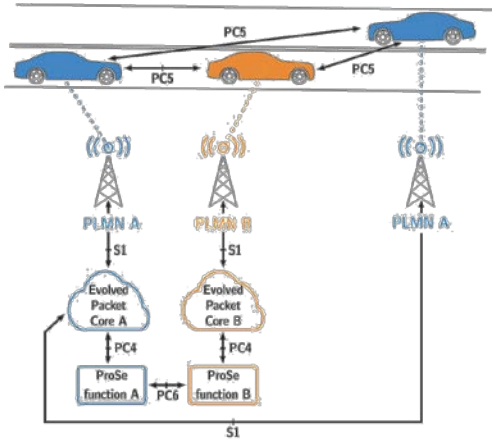


Cellular LTE-V2X

- **Since 3GPP LTE Rel. 14**
  - LTE-V2X operation
    - Sub-group of Proximity Service (Prose)
  - Provides Dedicated communication services:
    - V2V – Vehicle-to-Vehicle
    - V2I – Vehicle-to-RSU
    - V2P – Vehicle-to-Pedestrian
    - V2N – Vehicle-to-Network

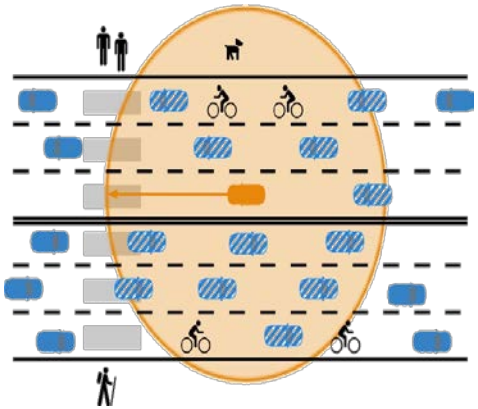


- **Architecture Extension:**
  - PC5 interface
  - V2X/ProSe Function/Applications
  - Two modes of Operations:
    - Managed (Mode 3) – eNB allocate resources
    - Ad-Hoc (Mode 4) – UEs self-allocate resources
      - ☞GPS-based Synchronization
      - ☞USIM-less operation

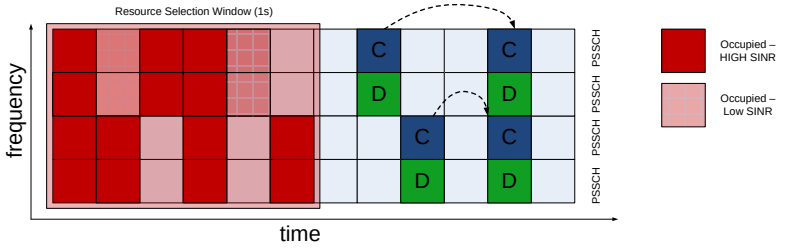


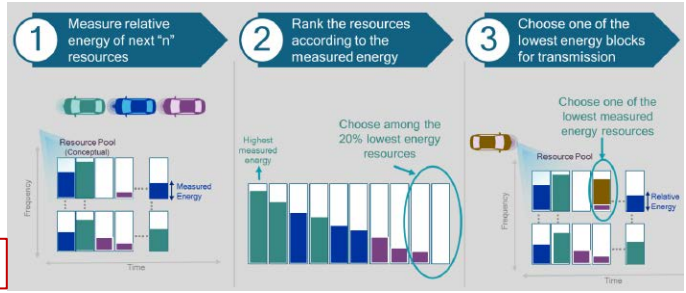
Cellular LTE-V2X - Mode 4

- **LTE-V2X mode 4 is a full ad-hoc**
  - Selected mode for Safety-related V2X communication



- **3GPP rel.14 mode 4 proposal:**
  - Semi-Persistent Scheduling
    - UE reserves RB over consecutive Sub-frames
  - Listen-before-Talk access
    - RSSI-based resource selection

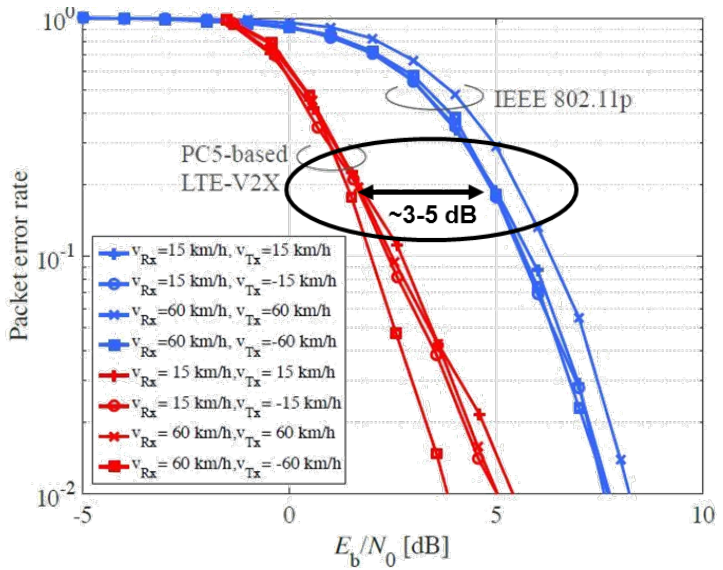




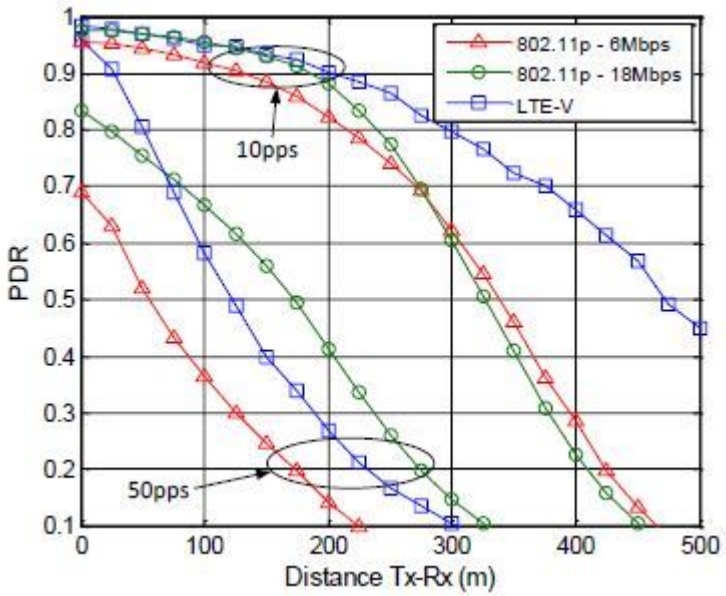
Source: Qualcomm

LTE-V2X vs. ITS-G5 – Comparison

- **Link-level vs. Packet-level Comparisons**



Source: J. Kenney et al., ITS-World Congress 2016

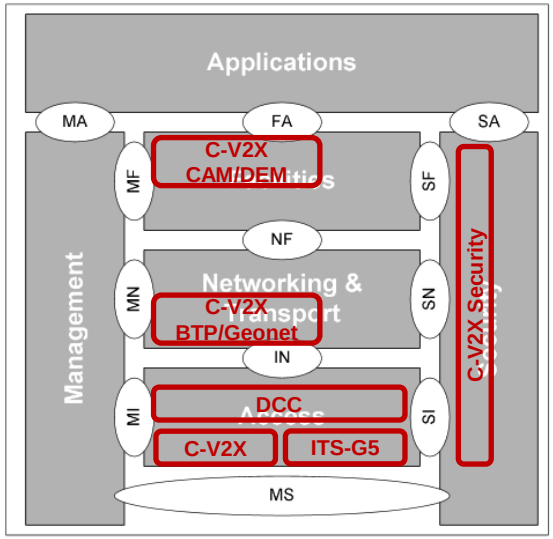


Source: R. M. Masegosa, J. Gozalvez, "LTE-V for Sidelink 5G V2X Vehicular Communications", IEEE Vehicular Technology Magazine, Dec. 2017

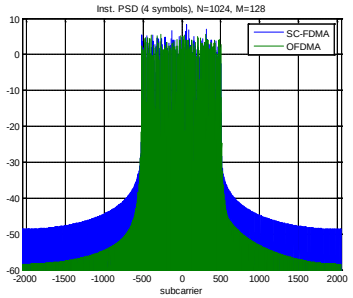
Disclaimer: **Not meant** to **advocate one technology over another**, but rather to **emphasize** the **complexity** of their **comparison** and true performance

Cellular LTE-V2X – Standardization Status

- **3GPP specification freeze in July 2017**
- **In January 2017, the CAR 2 CAR initiated a WI on LTE-V2X**
  - CAR 2 CAR White Paper – “Technical Evaluation and Open Issues”
- **Objectives:**
  - Introduce new concepts behind LTE-V2X
  - Define common scenarios and parameters
  - Identify required architecture extension
  - Gather open challenges
- **In October 2017, Cellular Stakeholders proposed multiple WI to ETSI ITS for LTE-V2X**
  - C-V2X is expected to be integrated in ETSI ITS in 2018
  - Access Technology -
    - LTE-V2X mode 3-4 rel.14 on PC5 for V2V
    - LTE-V2X on Uu for V2I/V2N communication



Coexistence ITS-G5 – LTE-V2X

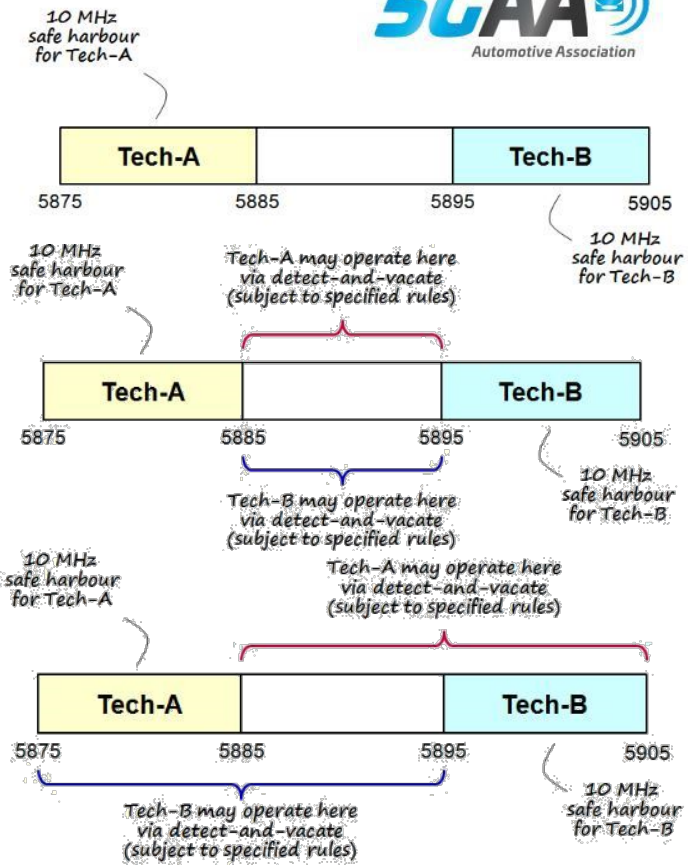


- **Based on the technology neutrality of the ITS-G5 band**
  - Both ITS-G5 and LTE-V2X can be granted access

- **Three phases coexistence:**
  - Phase 1 – LTE-V2X and ITS-G5 on different 10Mhz isolated bands
  - Phase 2 – LTE-V2X and ITS-G5 may coexist on additional shared band based on 'detect and avoid'
  - Phase 3 – LTE-V2X and ITS-G5 coexist on the full ITS-G5 band based on the detect and avoid mechanism

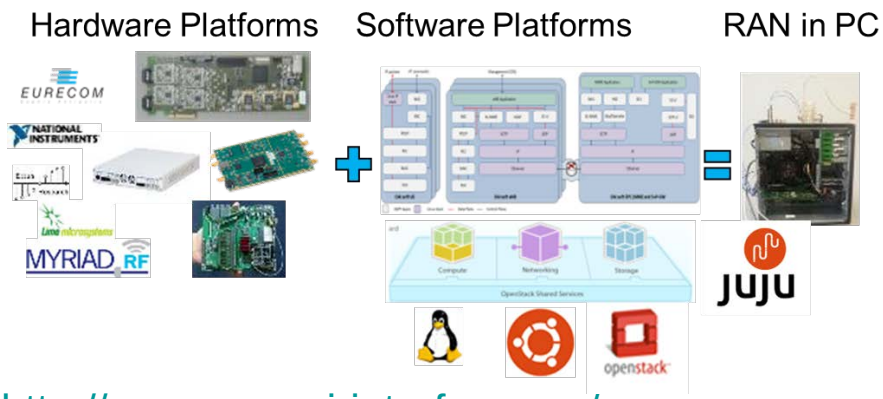
source:

5GAA Automotive Association



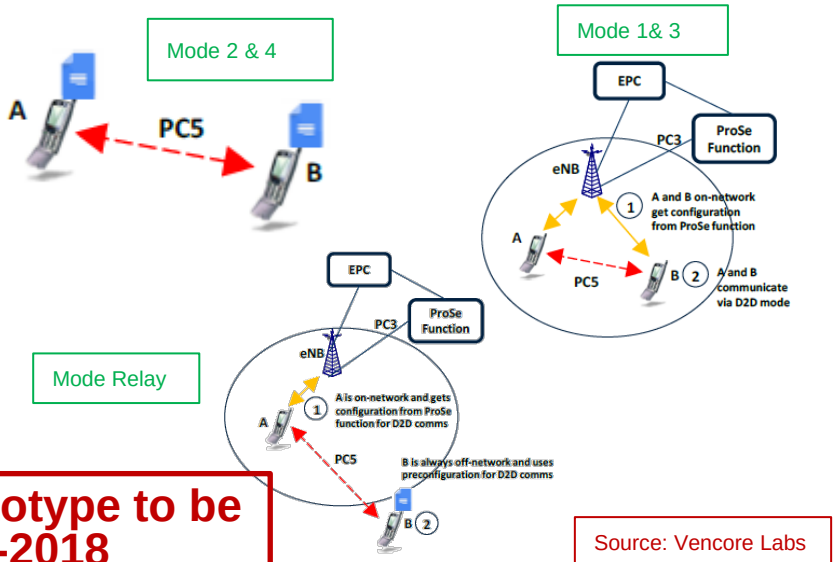
Cellular LTE-V2X on OpenAirInterface

- **Extension of OAI for Slidelink communication**
  - LTE Rel.14 compliant
  - Supporters:
    - Orange Labs
    - Vencore Labs (US)
  - Objective: 1st Open V2X/D2D Platform



http://www.openairinterface.org/

- **Architecture Extension:**
  - New emulation architecture
    - Toward dense UE networks
  - New procedures:
    - New Sidelink PHY
    - MAC/RRC Distributed Scheduling
  - Operation Mode:
    - LTE Prose Public Safety
      - Mode 1 & 2
      - LTE Relay mode
    - LTE-V2X
      - Mode 3 & 4



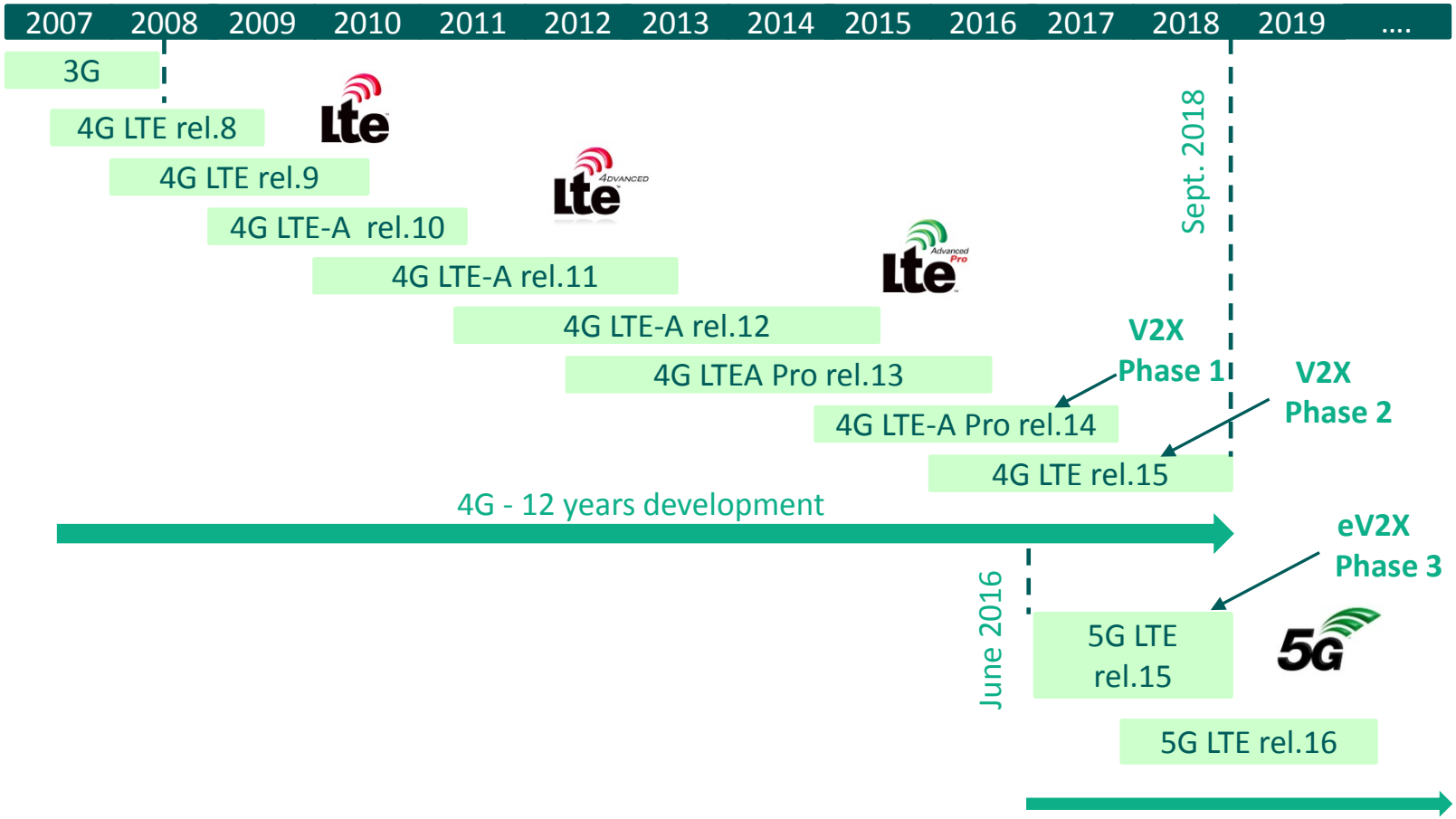
First 'Open' prototype to be ready mid-2018

Source: Vencore Labs

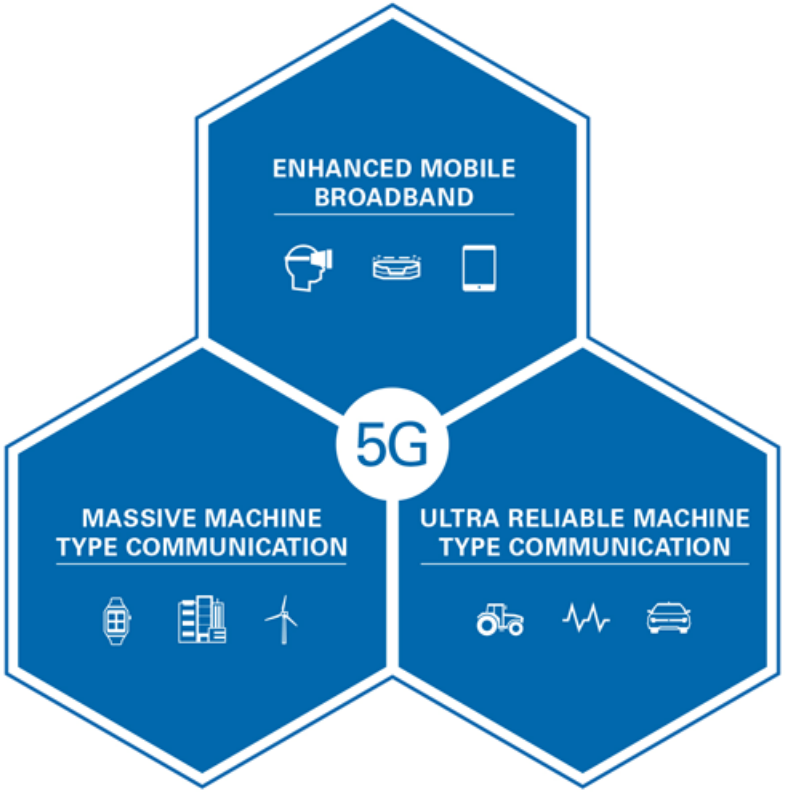
V2X Technologies

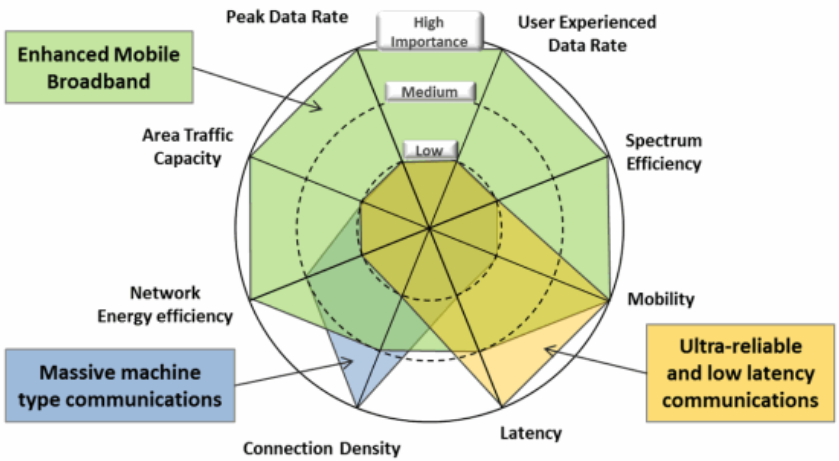
MOVING TOWARD 5G

Cellular V2X – 3GPP Roadmap



IMT Definition and Requirements for 5G



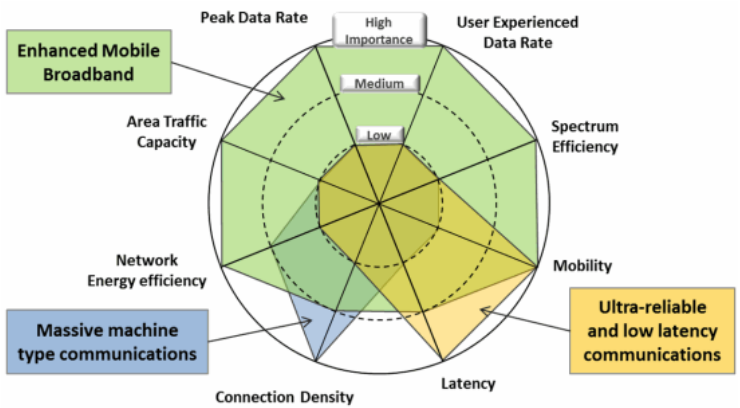


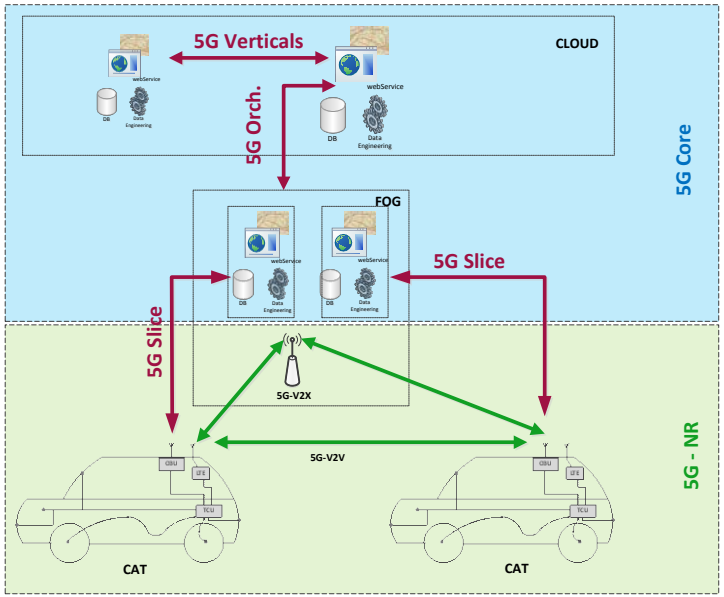
Attribute	IMT-Advanced 4G	IMT-Future 5G
Achievable Rate	1 Gbps	10-50 Gbps
Connection Density		10^6-10^7/km^2
Mobility & Coverage	350km/h	500km/h
Energy Efficiency	1x	50x – 100x
Spectral Efficiency	1x	5x-15x
Latency	10ms	1ms

Source: ITU

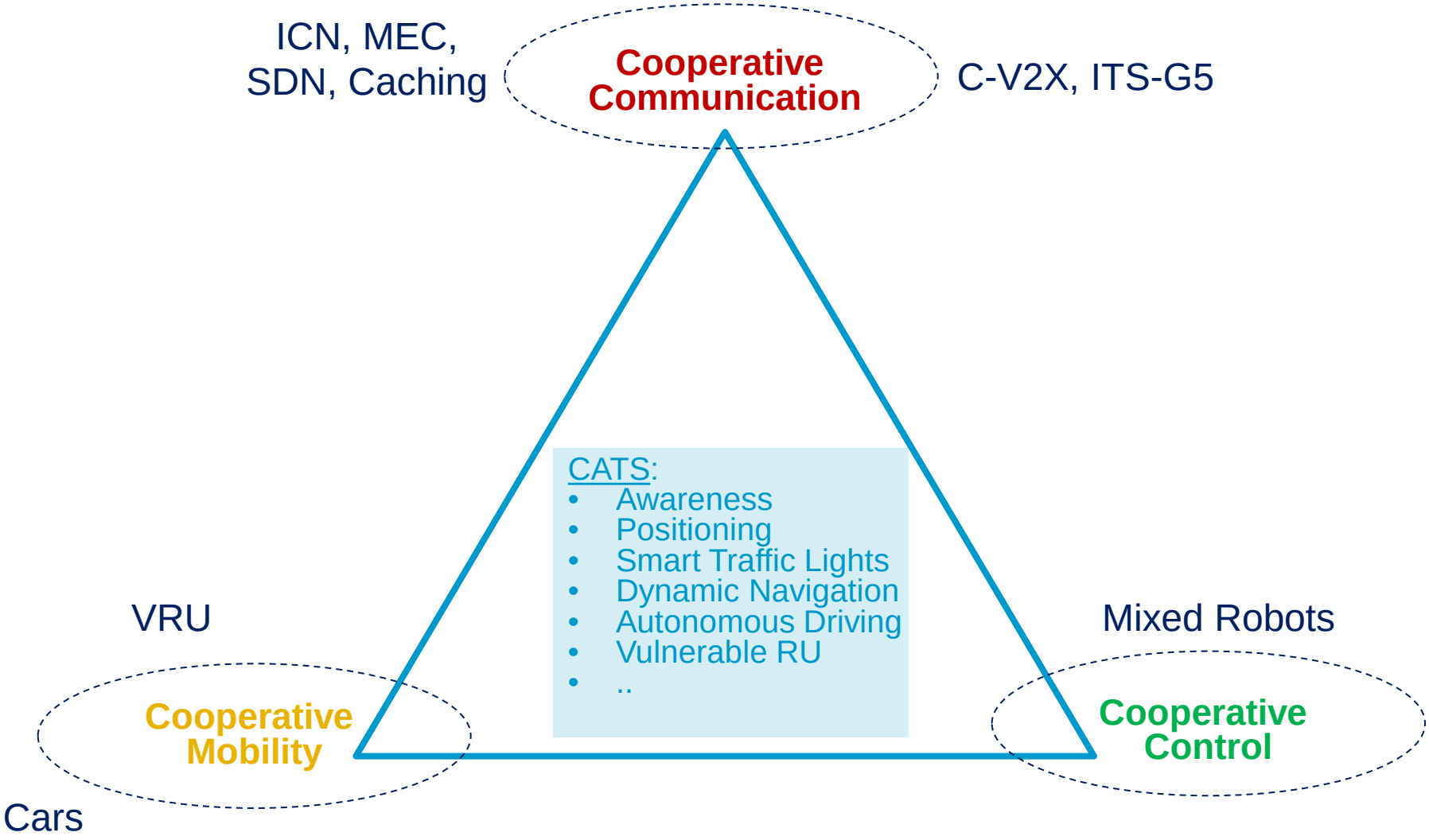
5G Challenges for Cooperative Connected Automated Vehicles

- **Key 5G Innovations**
  - URLL Communication
  - eMBB Communications
- **3GPP roadmap mostly on V2I (5G phase 1)**
  - 5G V2V not to evolve significantly
- **Critical role of 5G Core**
  - Mobile Edge Services
  - Network Slices
  - Cooperative ‘Infrastructure’
- **Key Message:**
  - 4G key innovation - V2V
  - 5G key innovation – URLL V2I



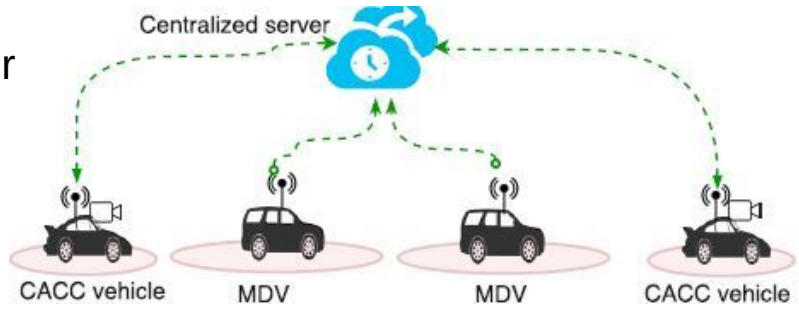


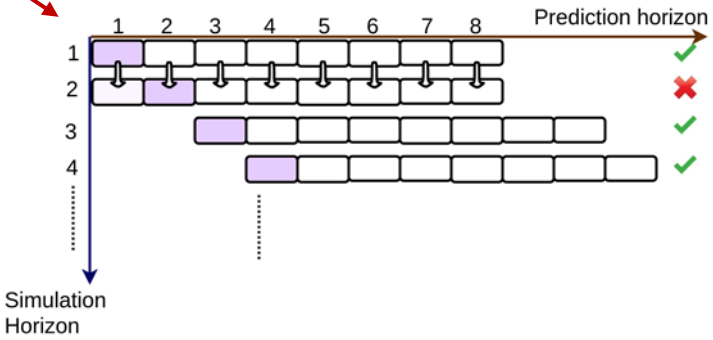
5G Challenges – Integrate Traffic and Control in a Triumvirate



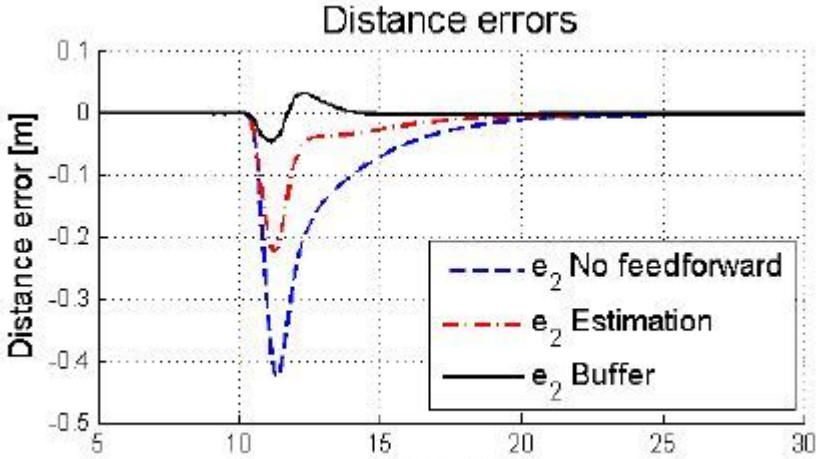
5G Challenges – Make Communication or Control more Robust ?

- **CACC subject to V2X Impairments**
  - Assumptions: 25Hz CAM / 100Hz controller
  - Block loss of CAMs
- **Impact on CACC**
  - Any CAM loss leads to dangerous situation…
  - But a more robust control strategy allows to mitigate it
- **Designing 5G V2X requires to match it with control mechanisms !!**





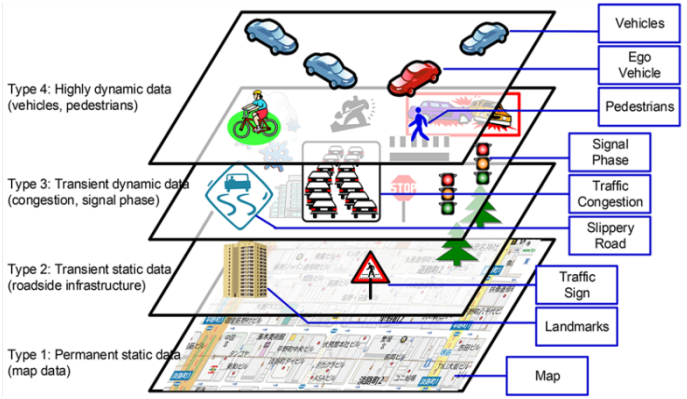
Source: R. Patel, J. Härri, C. Bonnet, **Impact of localization errors on automated vehicle control strategies,** IEEE VNC 2017.



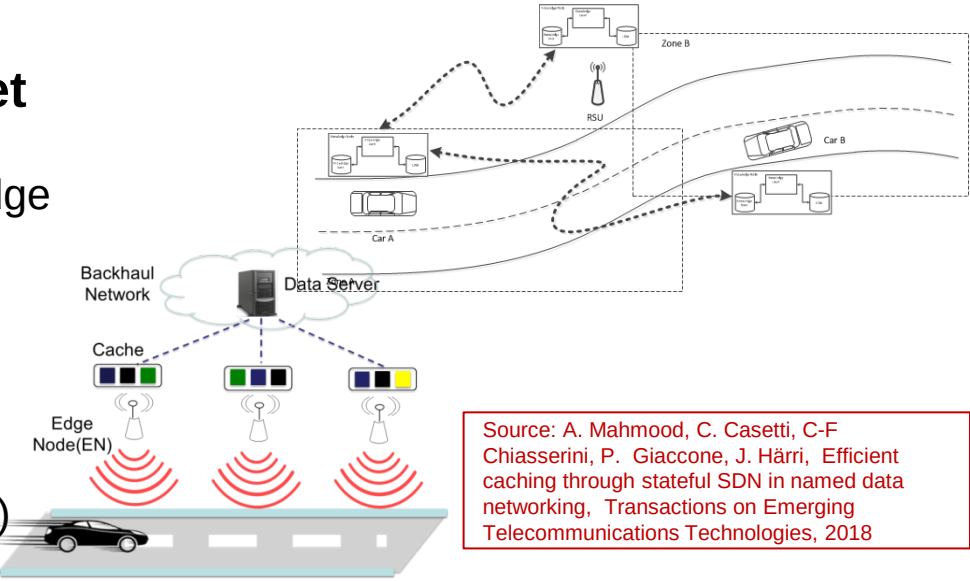
Source: Ellen van Nunen et al. , **Robust Model Predictive Cooperative Adaptive Cruise Control Subject to V2V Impairments**, IEEE ITSC 2017

5G Challenges – Information and Knowledge Layer

- **Local Dynamic Maps (LDMs)**
  - Critical feature of C-ITS
  - Stores information related to C-ITS applications
    - HD-map
    - Vehicles
    - Landmarks, road works
    - traffic congestions
    - ..
  - Yet: does not store Knowledge !!
- **Knowledge is required to interpret Information**
  - No current specification for a Knowledge base
- **LDM and Knowledge need to be exchanged and synchronized for future CATS**
  - 5G Mobile Edge Caching (MEC)
  - 5G Content-Centric Networking (CCN)
  - 5G Software Defined Networks (SDN)



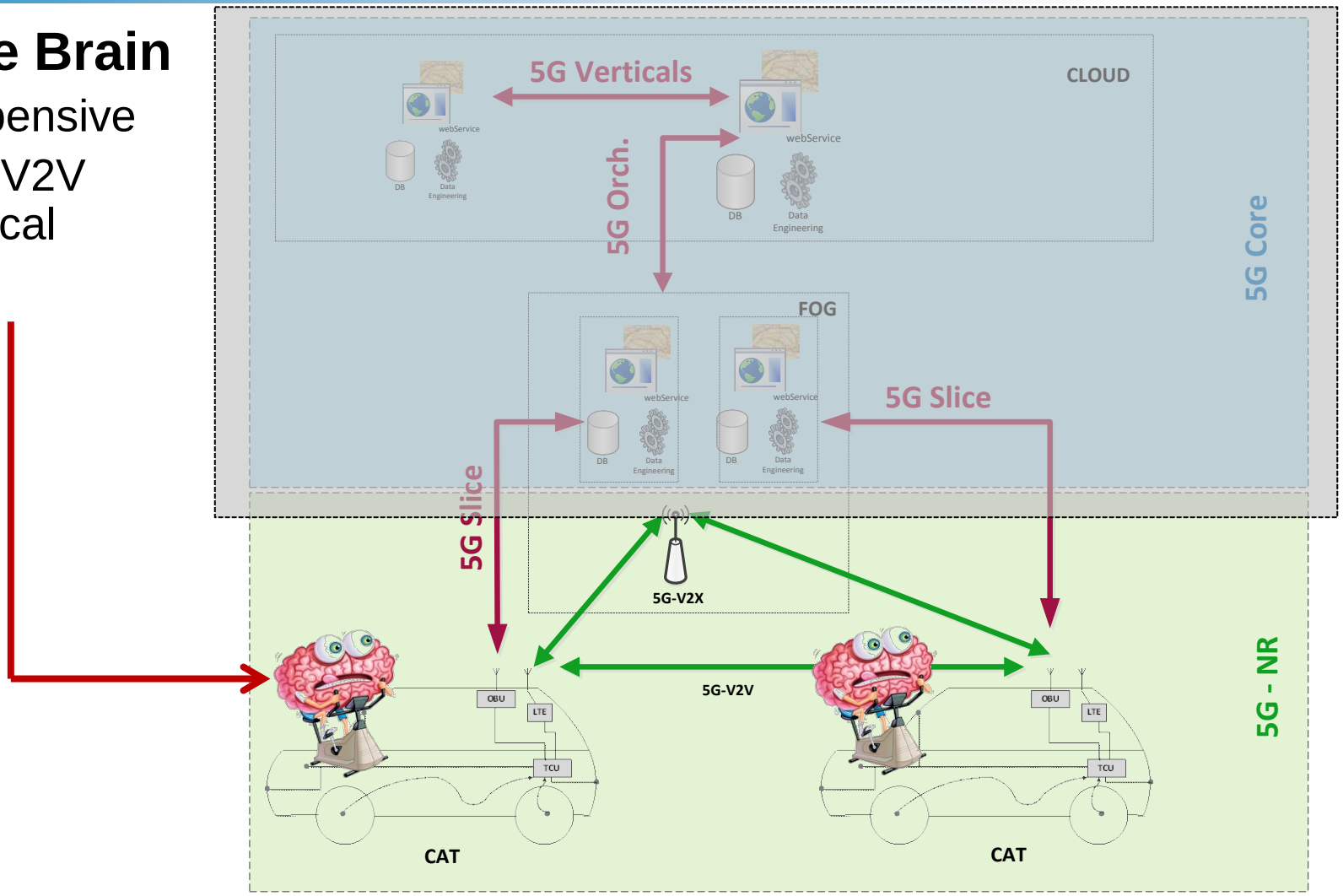
Source: Safespot Project



Source: A. Mahmood, C. Casetti, C-F Chiasserini, P. Giaccone, J. Härri, Efficient caching through stateful SDN in named data networking, Transactions on Emerging Telecommunications Technologies, 2018

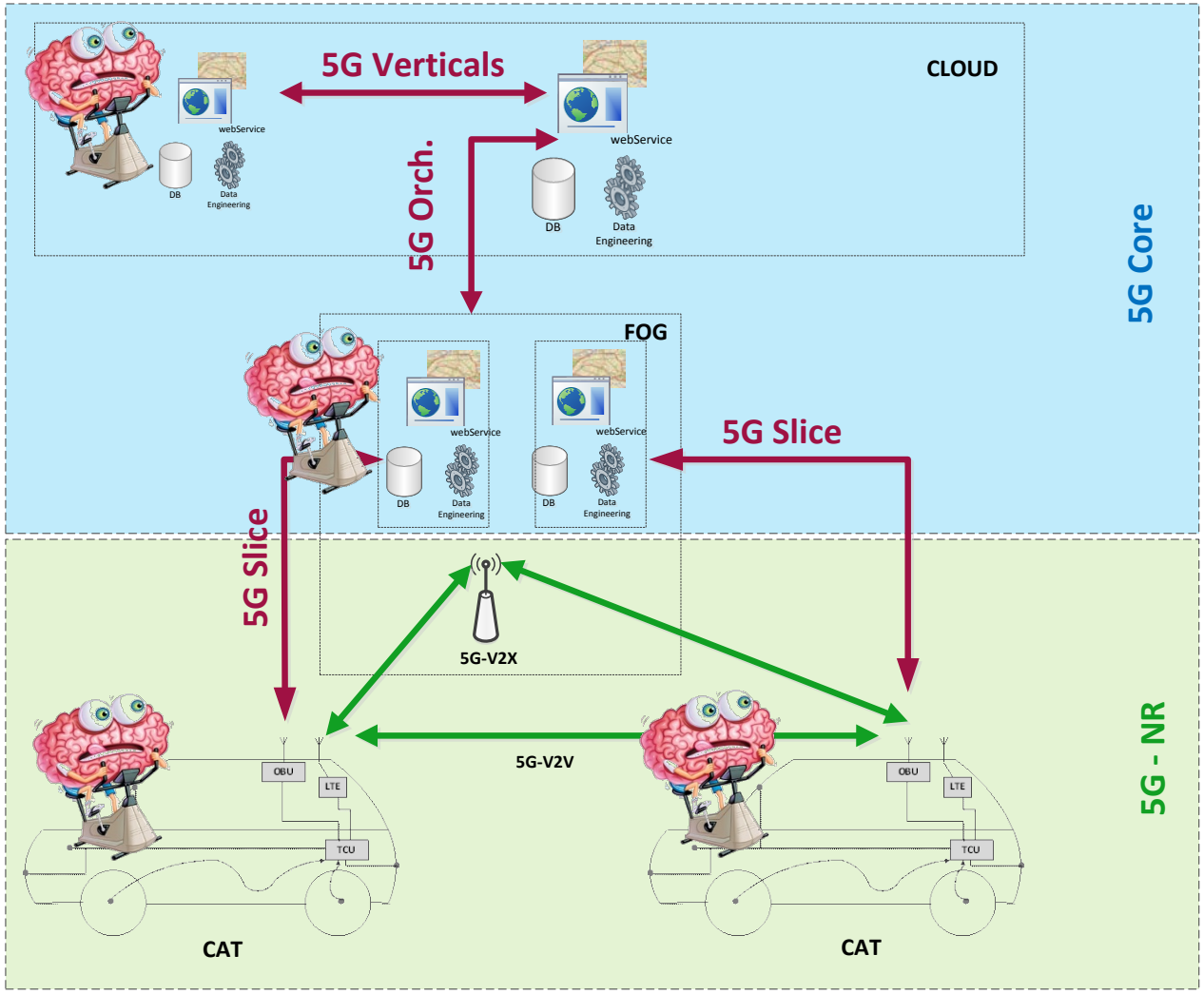
5G Challenge – Where to put the 'Brain' ?

- **Single Brain**
  - Expensive
  - 5G V2V critical



5G Challenge – where to put the 'Brain' ?

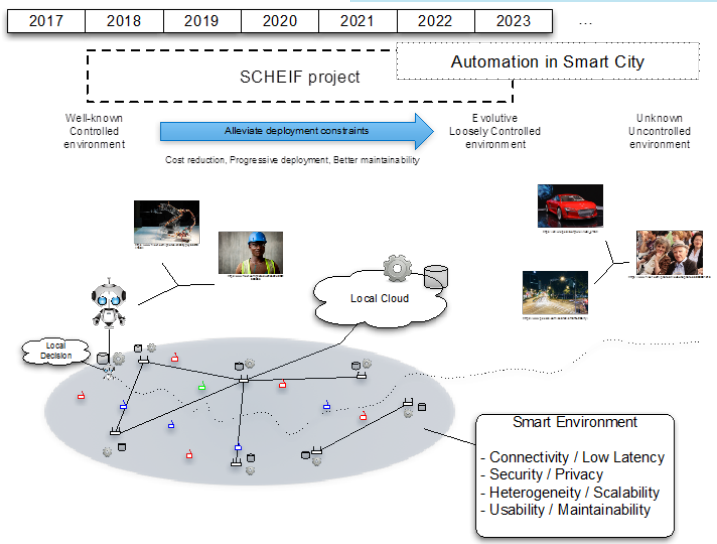
- **Split Brain**
  - Distributed efforts
  - 5G Core critical



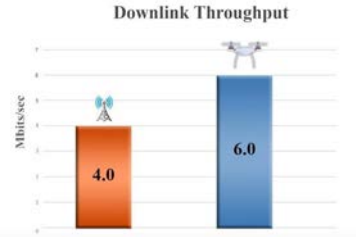
Cooperative Connected Automated Transport Systems – not only vehicles…

- **Bring 5G-V2X to Industry 4.0**
  - Decentralized Production Control
  - Evolving Production Environment
  - Plug-and-Produce
  - Hybrid-level Cooperation
  - Secured and resilient

AFA: - http://www.scheif.org



- **Drones to enhance 5G-V2X**
  - Drone act as 5G eNBs
    - Find optimal position to maximize capacity/reliability
  - Drone follow traffic



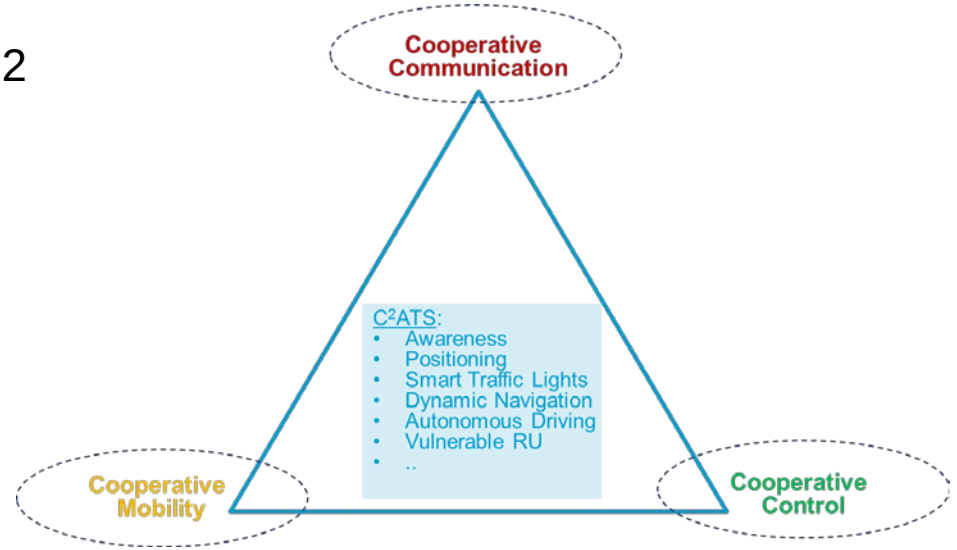
Source: Prof. Gesbert, ERC Perfume

Conclusions

- **5G for Cooperative Connected and Automated Vehicles**
  - Radically changes how 5G-V2X systems will operate
    - V2I most innovation
    - 5G MEC for near vehicle control
    - 5G Slice for multi-feeds control
- **Extensions of current Solutions**
  - ITS-G5 is moving toward a Release 2
  - C-V2X will soon be ready as well

Jérôme Härri, haerri@eurecom.fr

- **Challenge (among others):**
  - Cooperative Connected Automated Vehicles have specific behaviors on 5G
    - Need to understand it to design 5G



BACKUP SLIDES

The CATS Team at EURECOM

- **Vehicular Traffic Modeling (cars, scooters, pedestrians)**
  - Vehicular Mobility Modeling
    - mixed cars/scooters modeling
  - Vehicular Control Modeling
    - mixed autonomous/legacy control modeling
- **Vehicular Communications (ITS-G5, 5G)**
  - Dependable Vehicular Communication (ITS-G5, C2X)
    - ITS-G5 1-hop broadcast & congestion control
  - High Precision Positioning and Mapping
    - Cooperative positioning (ITS-G5, IR-UWB…)
  - 5G extensions to automotive domain
    - LTE D2D/V2X for safety communication
- **Vehicular Networking (Edge, SDN & NFV, IoX)**
  - SDN-based and Information-Centric Networking
  - Edge Caching & Computing
  - Device-centric Vehicular Networking
- **Automated Vehicles**
  - Platooning & cooperative adaptive cruise control (CACC)
  - Cooperative maneuvering and navigation

- **Vehicular Standardization Bodies**
  - 3 STF ETSI ITS, C2C CC WG COM co-chair and subWG DCC chair
  - OneM2M / W3C WoT standards
  - IETF IPWAVE
  - 3GPP

The CATS Team - Related Publications

- **WiFi V2X**
  - Miguel Sepulcre, Javier Gozalvez, Jérôme Härri, Hannes Hartenstein, Contextual Communications Congestion Control for Cooperative Vehicular Networks, IEEE Transaction on Mobile Computing, 2011.
  - Bernhard Kloiber, Jérôme Härri, Thomas Strang, Stefan Sand, Cristina Rico Garcia, "Random Transmit Power Control for DSRC and its Application to Cooperative Safety", *IEEE Transaction of Dependable and Secured Communication*, 2015
  - Irfan Khan, Gia-Minh Hoang, Jérôme Härri, Rethinking Cooperative Awareness for Future V2X Safety-Critical Applications, IEEE Vehicular Networking Conference (VNC), Turin, 2017.
  - Jérôme Härri, Matthias Alles, Friedbert Berens, IEEE 802.11p Extension Roadmap, Car 2 Car COM/ARCH, 11/29/2017.
- **Cellular V2X**
  - Laurent Gallo, Jérôme Härri, A LTE-direct broadcast mechanism for periodic vehicular safety communications, IEEE Vehicular Networking Conference (VNC), 2013.
  - Laurent Gallo, Jérôme Härri, Unsupervised LTE D2D -– Case Study for Safety-Critical V2X Communications, IEEE Vehicular Technology Magazine, 2017.
  - Laurent Gallo, Jérôme Härri, Distributed Radio Resource Management for Ad-Hoc LTE-V2X Automotive Safety Broadcast, Elsevier Vehicular Communication, Under Review, 2017.
  - Laurent Gallo, Jérôme Härri, Analysis of a S-TDMA Distributed Scheduler for Ad-Hoc Cellular-V2X Communication, IEEE Elsevier Ad-Hoc Networks, Under Review, 2018.
- **ADAS**
  - Raj Haresh Patel, Jérôme Härri, Christian Bonnet, Impact of localization errors on automated vehicle control strategies, IEEE Vehicular Networking Conference (VNC), Turin, 2017
  - Raj Haresh Patel, Jérôme Härri, Christian Bonnet, A collision mitigation strategy for intelligent vehicles to compensate for human factors affecting manually driven vehicles, IEEE Conference on Intelligent Transportation Systems, Yokohoma, 2017.
  - Sosina Gashaw, Paola Goatin, Jérôme Härri, Modeling and Analysis of Mixed Flow of Cars and Powered Two-wheelers, Elsevier Transportation Research Part C, 2018

ETSI ITS Innovative Work Items

- **TR 102 638 BSA Release 2 (incorporation of the new services)**
- **TS 102 890-2 (EN 302 890-2) Facility Position and Time**
- **TS 103 141 Facility Communication Congestion Control**
- **TR 103 298 Platooning pre-standardisation study**
- **TR 103 299 C-ACC pre-standardisation study**
- **TR 103 300-1 VRU pre-standardisation study**
- **TS 103 300-2 VRU Architecture**
- **TS 103 300-3 VRU Service**
- **TR 103 562 Informative Report Collective Perception**
- **TS 103 324 Collective Perception Service**
- **TS 103 561 Maneuver Coordination Service**
- **TR 103 579 Charging/Tolling applications via ITS-G5 pre-standardisation study**
- **TR 103 439 Multi Channel Operation study**

LTE V2X - List of Standards (all Rel. 14)

- ***V2X***
  - TS 36 300 - Evolved Universal Terrestrial Radio Access Network (E-UTRAN)
  - TS 36.101 - User Equipment (UE) radio transmission and reception
  - TS 23.285 - Architecture enhancements for V2X services
  - TS 22.185 - Service requirements for V2X services;
  - TS 22.186 - Enhancement of 3GPP support for V2X scenarios;
  - TS 24.386 - User Equipment (UE) to V2X control function; protocol aspects
- ***RRC signaling***
  - *TS 36.331 – E-UTRA Radio Resource Control (RRC);Protocol specification*
- ***PDCP Procedures***
  - *TS 36.323 – E-UTRA Packet Data Convergence Protocol (PDCP) specification*
- ***MAC layer Procedures***
  - *TS 36.321 – E-UTRA* Medium Access Control (MAC) protocol specification
- ***Physical Layer Procedures***
  - *TS 36.211 – E-UTRA Physical Channels and Modulations*
  - *TS 36.212 - E-UTRA Multiplexing and channel coding*
  - *TS 36.213 – E-UTRA* Physical layer procedures
  - *TS 36.214 – E-UTRA Physical Layer - measurements*